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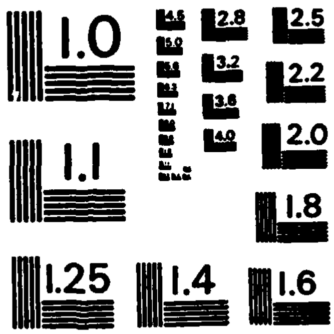
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THE RESPONSE OF THE HIGH LATITUDE IONOSPHERE TO CONVECTION ELECTRIC FIELDS

W.J. Raitt

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This report summarizes work done in developing and using a time-dependent computer model of the convecting high-latitude ionosphere to provide maps of the plasma density distribution as a function of altitude, local time, universal time and latitude for ranges of the geophysical parameters of season, geomagnetic activity and solar cycle.

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1. Introduction

A direct consequence of the theory describing the formation of the earth's magnetosphere is the concept of a large scale electric field which, by being mapped by the earth's magnetic field will cause plasma motion in the polar regions of the earth. This plasma motion is sometimes called convection, and the electric field driving the plasma motion is often referred to as the convection electric field. When looked at on a fine scale both temporarily and spatially the motion of the plasma is very complex, however a general pattern is clear involving antisunward flow of ionospheric plasma from noon to midnight over the polar cap, and a return, sunward, flow from midnight to noon at lower latitudes, producing a two-cell convection pattern.

The convection electric field driving the plasma is linked to the geomagnetic field, the pole of which is offset from the geographic pole and rotates about the geographic pole once per day. The combination of the oscillatory convection flow and the tendency of plasma to corotate at lower latitudes produces complex patterns of flow, even on the large scale of the whole polar region. There is rapid motion of the plasma in some places and stagnation at others. This type of flow pattern produces major effects on the ionospheric plasma density and composition at high latitudes.

The work associated with this contract was directed to the study of these effects on the high latitude ionosphere. The work fell into three broad categories:

i) Steady state studies of the altitude profile of high latitude ionospheric composition for a wide range of geophysical conditions.

ii) A mathematical model of the average convection electric field with universal time dependence included and the consequent plasma flow characteristics.

iii) Development of a comprehensive time dependent high-latitude

ionospheric plasma model by combining the work developed in i) and ii).

In addition to the theoretical modelling work, comparisons were made with experimental results relating both to convection trajectories and to the ionospheric plasma density and composition. In the cases studied the experimental results showed good agreement with the theoretical model.

2. Steady State High-Latitude Ionospheric Model

In order to more accurately reflect the chemical and diffusion processes governing the plasma in the high-latitude ionosphere we extended a model developed earlier (Schunk et al, 1975, 1976) to include N^+ in addition to NO^+, O_2^+, N_2^+ and O^+, and to use representative He^+ profiles derived from earlier He^+ outflow studies (Raitt et al, 1978a, 1978b). The model allowed for Joule heating due to plasma convection through the neutral atmosphere; it included the latest MSIS model atmosphere (Hedin et al, 1977a, 1977b) and an empirical model for N (Engebretson et al, 1977); recently published solar UV fluxes were included (Hinteregger et al, 1977); and the latest values for ion chemistry reaction rates were used.

The model was used to calculate the variability in the high-latitude ionospheric composition under steady state day-time conditions for ranges of geophysical parameters. The parameters we varied were season, geomagnetic activity, and solar cycle. Details of the results are given in the paper "Atomic Nitrogen Ions and Oxygen Ions in the Daytime High-Latitude F-Region" by R.W. Schunk and W.J. Raitt included in appendix A.

The steady state model developed formed the basis of the time dependent model to be used in conjunction with a model for plasma convection resulting from the magnetospheric electric field being mapped into the ionosphere.

3. High-Latitude Plasma Convection Model

It is generally accepted that a large scale electric field exists from dawn to dusk across the flanks of the earth's magnetosphere. This electric field maps to the polar ionosphere along geomagnetic field lines and causes an $\bar{E} \times \bar{B}$ drift of ionospheric plasma in a two-cell pattern over the polar cap and to lower latitudes determined by the extent of the penetration of the magnetospheric electric fields into mid-latitudes. Detailed studies of this pattern by experimental observations indicate a great deal of temporal and spatial fluctuations. However, the general average pattern is as described above, and in the work performed under this contract we were aiming to look at the background conditions of convection and the resulting effects on the high-latitude ionospheric plasma rather than study the fine detail resulting from small scale perturbations to the convection pattern.

In the absence of a convection electric field, the plasma is driven to corotate with the earth's atmosphere. Viewed from an inertial reference frame the net motion of the plasma is a combination of corotation and convection resulting in a stagnation region on the dusk/evening side of the polar regions. The motion of the plasma is further complicated by the offset between the geographic and geomagnetic poles resulting in a diurnal variation of either corotation or convection depending if the plasma motion is viewed in a geomagnetic or a geographic inertial frames respectively.

Detailed studies of the motion using a model in which the strength, mapping region, and symmetry of the magnetospheric electric field were made. The results of this study are described in the paper entitled "Effect of Displaced Geomagnetic and Geographic Poles on High-Latitude Plasma Convection and Ionospheric Depletions" by J.J. Sojka, W.J. Raitt, and R.W. Schunk included in appendix A to this report. As a follow up to this study predictions were made for the convection velocities expected at high-latitude radar back-scatter stations at EISCAT and Sondre Stromfjord in the paper "High-Latitude Plasma Convection predictions for EISCAT and Sondre Stromfjord" by J.J. Sojka,

W.J. Raitt, and R.W. Schunk included in appendix A. A comparison with actual convection velocity data made by the incoherent scatter radar at Chatinika was made and is described in the paper "High-Latitude Convection: Comparison of a simple model with incoherent scatter observations" by J.J. Sojka, J.C. Foster, W.J. Raitt, R.W. Schunk, and J.R. Doupnik also included in appendix A. The final study of the predictions of the convection model was to compare ionospheric convections in the northern and southern polar regions. This comparison showed a considerable difference largely due to the different displacements of the north and south geomagnetic poles from their respective geographic poles. Details of this comparison are given in the paper "A Comparison of Model Predictions for Plasma Convection in the Northern and Southern Polar Regions" by J.J. Sojka, W.J. Raitt, and R.W. Schunk included in appendix A.

In general we found that although our magnetospheric convection model needed few parameters to define it, it predicted many of the convection features seen by satellite observations and incoherent scatter radar observations. In particular it threw light on some of the problems associated with interpolating convection velocities over the whole polar cap based on satellite traverses taken at different universal times.

As a result of these studies we felt that we were in a position to combine this convection model with the ionospheric model described in section 2 and develop a computer program which enabled us to follow packets of plasma as they moved in the high latitude region under the combined influence of the convection electric field and corotation forces.

4. Time Dependent High-Latitude Model

A computer model was developed to follow packets of plasma from a steady state noon altitude profile of the various ion species forming the high-latitude ionosphere as they convected around the high-latitude regions at varying speeds and in varying directions. By selecting sufficient trajectories and allowing the plasma to move for a period of 1 1/3 days (to accomodate

trajectories passing near the stagnation region) a map of ionospheric plasma composition over the altitude range 150-800 km as a function of latitude, local time, and universal time was built up.

The extent of the computations and the amount of data accumulated was such that the large computer resources of the CRAY-1 at NCAR were required. A comprehensive survey of the polar and mid-latitude regions for a given set of geophysical conditions generated approximately 20,000 altitude profiles for each of the six ions considered in our model.

This large amount of data was compressed for presentation by binning in the three variables, UT, local time, and altitude and presenting the data as contour plots supported by detailed altitude plots to emphasize certain features of the results.

At present we have studied the high latitude ionosphere with our model for the following geophysical conditions:

i. Winter, solar minimum, low magnetic activity.

ii. Winter, solar minimum, high magnetic activity.

iii. Summer,, solar minimum, high magnetic activity.

The results of these studies have been published in the following papers which are included in appendix A. "A Theoretical Study of the High-Latitude Winter F-Region at Solar Minimum for low Magnetic Activity" by J.J. Sojka, W.J. Raitt, and R.W. Schunk, "Theoretical Predictions for Ion Composition in the High-Latitude Winter F-region for Solar Minimum and Low Magnetic Activity" by J.J. Sojka, W.J. Raitt, and R.W. Schunk, "Plasma Density Features Associated With Strong Convection in the Winter High-Latitude F-Region" by J.J. Sojka, W.J. Raitt, and R.W. Schunk, "Seasonal Variations of the High-Latitude F-Region for Strong Convection" by J.J. Sojka, R.W. Schunk, and W.J. Raitt. In addition to the comparison of model predictions with experi-

mental observations have been made using data from the DMSP satellites which provided good experimental confirmation of the UT effect predicted by the model. These results are detailed in the paper "Observations of the Universal Time Dependence of the High-Latitude F-region Ion Density by DMSP Satellites" by J.J. Sojka, W.J. Raitt, R.W. Schunk, F.J. Rich, and R.C. Sagalyn included in appendix A.

The present state of our modelling work has been summarized in three review papers; "Modelling the High-Latitiude Ionosphere" by W.J. Raitt, R.W. Schunk, and J.J. Sojka, "High-Latitude Ionospheric Model: First Step Towards a Predictive Capability" by R.W. Schunk, W.J. Raitt and J.J. Sojka, "Composition and Characteristics of the Polar Wind" by W.J. Raitt and R.W. Schunk which are included in appendix A.

5. Conclusions and Recommendatons

We feel that in recent years there have been considerable advances in our understanding of the physical processes resulting in the dynamic behavior of the high-latitude ionosphere evidenced by the complex nature of high-latitude ionospheric measurements. The work described in this report has brought our research to the point where we believe we have a tool to enable predictions to be made for the high-latitude F-region both for operational uses, and to interpret measurements.

We have just started to study the geophysically imposed limits expected of average high-latitude ionospheric behavior. This aspect of the work should be completed by studying other combinations of season, geomagnetic activity, and solar cycle which have not yet been studied using our model.

The present model does not have provision to include the short term effects of magnetospheric substorms. We believe this feature can be added to the model and should form part of continuing studies in this area, since the short term effects can result in very marked changes in the propagation char-

acteristics of the F-region for short periods of time.

In summary therefore, we feel that this study has advanced our knowledge of the physical processes occuring in the high-latitude ionosphere to the point that a model of practical use could be developed. We recommend that the work be continued to explore the limits of the average behavior of the high-latitude ionosphere and that the effects of magnetospheric sub-storms should subsequently be included. Finally the data sets produced by the various combinations of geophysical parameters should be used with an interpolation to enable a rapid assessment of high-latitude ionospheric conditions to be made for any combination of the geophysical parameters which have a major effect on the ionospheric properties.

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Additional Scientists Contributing to Research

1) Professor P.M. Banks*, Utah State University

2) Professor R.W. Schunk, Utah State University

3) Dr. J.J. Sojka, Utah State University

4) Dr. J.L. Parish, Utah State University

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APPENDIX A

List of published papers relevant to the contract.

Raitt, W. J., R. W. Schunk, and J. J. Sojka, "Modelling the High-Latitude Ionosphere", The Physical Basis of the Ionosphere in the Solar Terrestrial System, AGARD conference proceedings No. 295, 9/1 - 9/14, 1981.

Raitt, W. J., and R. W. Schunk, "Composition and Characteristics of the Polar Wind", Energetic Ion Composition in the Earth's Magnetosphere, Ed. R. G. Johnson, 1982.

Schunk, R. W., and W. J. Raitt, "Atomic Nitrogen and Oxygen Ions in the Daytime High-Latitude F-Region, J. Geophys. Res., 85, 1255-1271, 1980

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MODELLING THE HIGH-LATITUDE IONOSPHERE

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ABSTRACT

Results of an ionospheric model program are presented which demonstrate the extreme variability of the steady state, daytime, ionospheric F-region electron density and ion composition due to both neutral atmospheric changes with solar cycle, season and magnetic activity, and to the effects of ionospheric drifts caused by perpendicular electric fields. Consideration is given to the time history of the ionospheric plasma as it undergoes convective motion due to the combined effects of co-rotation forces and electromagnetic forces, which results from the mapping of the magnetospheric cross-tail electric field to the rotating ionosphere. A simple model of the convection pattern is described. The model calculates the net effect of the tendency for the plasma to co-rotate about the geographic pole and the $\underline{E} \times \underline{B}$ velocity induced by a perpendicular electric field mapped to a circle centered about a point 5^{o} anti-sunward of the geomagnetic pole and oriented such that the equipotentials are parallel to the noon-midnight meridian. This convection pattern shows the generally accepted features of high latitude convection, but because of the offset between the geographic and geomagnetic poles a marked universal time dependence in these features is predicted. The results of a comparison of the convection model with ground-based incoherent scatter radar measurements from Chatanika and Millstone Hill are shown to be in good general agreement. In addition, differences in the convection pattern between the northern and southern polar ionospheres are shown to be important, particularly in the case of asymmetric magnetospheric electric fields. Finally, maps are shown of the modelled ionospheric composition and density for a convecting polar ionosphere demonstrating the formation of commonly observed features such as the mid-latitude trough and the polar hole, and their dependence on universal time.

"Composition and Characteristics of the Polar Wind"

W. J. Raitt and R. W. Schunk

ABSTRACT

We have discussed in general terms the mechanism of the polar wind, describing a pressure gradient driven flow of light ions (H^+, He^+) from a source region around 300 km altitude to the outer regions of the magnetosphere along geomagnetic field lines. Although it is pointed out that the dynamical nature of the high-latitude ionospheric source will result in an outward flux of light ions which is both spatially and temporally variable, the average value is generally accepted to be of the order of $3 \times 10^8 cm^{-2} sec^{-1}$ for H^+ ions and $2 \times 10^7 cm^{-2} sec^{-1}$ for He^+ ions.

The results of detailed theoretical models of H^+ and He^+ outflow are presented. The resulting density, temperature and velocity profiles are examined under a variety of conditions to bracket the range of values which might be expected to be encountered in the terrestrial environment. Recent developments of the theoretical modeling of light ion outflow are discussed, in which changes are predicted in the distribution function of the polar wind species in terms of temperature differences parallel and perpendicular to the magnetic field direction.

The final section collects together the published experimental evidence for the polar wind. The measurements exist only in the upper ionosphere and consist of either direct observations of the flow velocity, or indirect observations in terms of differences in the light ion density at a given altitude between low latitude regions of little or no outflow, and polar regions where a strong outflow is expected.

The principal conclusion presented in the paper is that polar wind studies represent a field of geophysical research in which theoretical modeling has far outstripped experimental observations. It is hoped that programs such as the existing ISEE and Dynamics Explorer projects and the proposed OPEN project will go some way to alleviate this deficiency.

ATOMIC NITROGEN AND OXYGEN IONS IN THE DAYTIME HIGH-LATITUDE F REGION

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Abstract. We have extended our high-latitude, ionospheric, dynamic model to include N^+ in addition to the ions NO^+, O_2^+, N_2^+, and O^+. The ion He^+ was also included but altitude profiles of this ion were obtained from our previous polar wind study. We have further improved our model by updating the various chemical reaction rates and by including the latest solar EUV fluxes measured by the Atmosphere Explorer satellites, the most recent MSIS model of the neutral atmosphere (N_2, O_2, O, and He) and the latest empirical model of atomic nitrogen. The improved model was used to study the solar cycle, seasonal, and geomagnetic activity variations of the daytime high-latitude F layer. Both zonal and meridional convection electric fields were considered. Without allowance for electric fields, the peak O^+ and N^+ densities varied by an order of magnitude and the altitudes of the peaks varied by about 100 km over the range of geophysical conditions studied. Convection electric fields can also produce about an order of magnitude change in the O^+ and N^+ densities. These electric field induced changes could either assist or oppose the solar cycle, seasonal, and geomagnetic activity variations depending on the ionospheric conditions. In general, N^+ was the second most abundant ion in the upper F region, but there were cases when He^+ was more abundant than N^+ even though He^+ was in a state of outflow. Also, we speculate that at times, N^+ can be the dominant ion in the upper F region.

High-Latitude Ionospheric Model: First Step Towards a Predictive Capability

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ABSTRACT

We combined a simple plasma convection model with an ionospheric-atmospheric composition model in order to simulate high-latitude ionospheric behavior. The convection model includes the offset between the geographic and geomagnetic poles, the tendency of plasma to corotate about the geographic pole, and a dawn/dusk magnetospheric electric field mapped to a circular region in the ionosphere about a center offset by a few degrees in the antisunward direction from the magnetic pole. The ionospheric-atmospheric composition model takes account of plasma convection, plasma diffusion, photochemical processes, thermospheric winds, and ion production due to both auroral precipitation and resonantly scattered solar radiation. A typical numerical simulation produces time-dependent, 3-dimensional, ion density distributions (NO^+, O_2^+, N_2^+, O^+, N^+ and He^+) for the high-latitude ionosphere above 42°N magnetic latitude and at altitudes between 160-800 km. One of the early results to emerge from the use of this numerical model was that high-latitude features, such as the 'main trough', the 'ionization hole', the 'tongue of ionization', the 'aurorally produced ionization peaks', and the 'universal time effects', are a natural consequence of the competition between the various chemical and transport processes known to be operating in the high-latitude ionosphere. In this investigation the numerical model was used to study the variations of the electron density with altitude, latitude, longitude, and universal time for ionospheric conditions corresponding to winter solstice and for convection electric field patterns that are representative of both low and high geomagnetic activity conditions. In addition, we studied the morphology of h_mF_2, N_mF_2, the F-region total electron density content, and the topside plasma density scale height.

EFFECT OF DISPLACED GEOMAGNETIC AND GEOGRAPHIC POLES ON HIGH-LATITUDE PLASMA CONVECTION AND IONOSPHERIC DEPLETIONS

J. J. Sojka, W. J. Raitt, and R. W. Schunk

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Abstract. We assumed that the ionospheric plasma at high latitudes has a tendency to corotate about the geographic pole and that magnetospheric convection is relative to the geomagnetic pole. With this assumption we calculated plasma drift patterns over the polar cap for a range of constant magnetospheric electric fields as well as for asymmetric electric fields with enhanced plasma flow on either the dawnside or the duskside of the polar cap. We calculated the drift patterns in both the geographic inertial and the geomagnetic inertial frame taking into account the displacement between the geographic and geomagnetic poles. We found that this displacement between the poles has an important effect on the plasma drift patterns. In particular, we found the following: (1) A time-independent magnetospheric electric field produces a flow pattern in the magnetic inertial frame that does not vary with universal time. (2) This flow pattern becomes UT dependent in the geographic inertial frame because of the motion of the geomagnetic pole about the geographic pole. (3) The UT variation of the plasma flow pattern in the geographic inertial frame occurs on a time scale that is comparable to satellite orbital periods and that is much less than typical plasma convection flow times over the polar cap. (4) In the geographic inertial frame the main region of very low speed flow is not centered at 1800 LT but moves from about 1300 to 2300 LT during the course of a day. (5) In the geographic inertial frame a throatlike feature appears at certain universal times owing to the relative motion of the geographic and geomagnetic poles. This feature is not seen in the geomagnetic inertial frame and is not connected with our model of the magnetospheric electric field. These results and others described in the paper have important implications for both the interpretation of satellite data related to high-latitude ionospheric dynamics and the formation of ionospheric troughs.

HIGH LATITUDE PLASMA CONVECTION: PREDICTIONS FOR EISCAT AND SONDRE STROMFJORD

J.J. Sojka, W.J. Raitt and R.W. Schunk

Center for Atmospheric and Space Sciences, Utah State University, Logan, Utah 84322

Abstract. We have used a plasma convection model to predict diurnal patterns of horizontal drift velocities in the vicinity of the EISCAT incoherent scatter facility at Tromso, Norway and for Sondre Stromfjord, Greenland, a proposed new incoherent scatter facility site. The convection model includes the offset of 11.4° between the geographic and geomagnetic poles (northern hemisphere), the tendency of plasma to corotate about the geographic pole, and a magnetospheric electric field mapped to a circle about a center offset by 5° in the anti-sunward direction from the magnetic pole. Four different magnetospheric electric field configurations were considered, including a constant cross-tail electric field, asymmetric electric fields with enhancements on the dawn and dusk sides of the polar cap, and an electric field pattern that is not aligned parallel to the noon-midnight magnetic meridian. The different electric field configurations produce different signatures in the plasma convection pattern which are clearly identified. Both of these high-latitude sites are better suited to study magnetospheric convection effects than either Chatanika, Alaska or Millstone Hill, Massachusetts. Also, each site appears to have unique capabilities with regard to studying certain aspects of the magnetospheric electric field.

HIGH-LATITUDE CONVECTION: COMPARISON OF A SIMPLE MODEL WITH INCOHERENT SCATTER OBSERVATIONS

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Abstract. We have compared a simple model of plasma convection at high latitudes with data obtained from simultaneous measurements made by the incoherent scatter facilities at Chatanika, Alaska and Millstone Hill, Massachusetts in June 1978 during moderately disturbed conditions. The measured horizontal plasma drift velocities were averaged for four days to emphasize gross features of the convection pattern and reduce the effects of substorms. The convection model includes the offset of 11.5° between the geographic and geomagnetic poles, the tendency of plasma to corotate about the geographic pole, and a constant dawn/dusk magnetospheric electric field mapped to a circle about a center offset by 5° in the anti-sunward direction from the magnetic pole. The radius of the circle corresponds to 17° of latitude and the electric potentials are aligned parallel to the noon/midnight meridian within the circle. Equatorward of the circle the potential diminishes radially and varies inversely as the fourth power of sine magnetic co-latitude. A consequence of these two offsets and the sunward alignment of the magnetospheric electric field is that our model predicts different diurnal convection patterns when viewed at different longitudes in the geographic frame. The concurrently observed diurnal distributions of horizontal plasma convection velocities are different for Chatanika and Millstone Hill even though the measurements cover approximately the same range of magnetic latitudes. We find there is good agreement between our simple model and the gross features of these two diurnal patterns.

A Comparison of Model Predictions for Plasma Convection in the Northern and Southern Polar Regions

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Abstract. We have presented model calculations to show how the plasma flow distributions in the northern and southern polar regions differ when viewed from a geographic inertial frame. Thus reference frame was selected because it is the natural frame for geophysical plasma flow measurements, there being well known velocity corrections for either satellite or ground-based observations. Although the magnetic invariant latitude, magnetic local time reference frame is better suited to studying magnetospheric processes, a transformation from the geographic inertial frame to this magnetic frame requires both a spatial and velocity transformation, and since the latter correction has generally been neglected, we prefer to present our results in the geographic inertial frame. However, we also present some of our results in the magnetic frame, taking account of the complete transformation. Our convection model includes the offset between the geographic and geomagnetic poles, the tendency of plasma to corotate about the geographic poles, and a dawn/dusk magnetospheric electric field mapped to a circle about a center offset by 5° in the antisunward direction from the magnetic pole. We considered both uniform and asymmetric magnetospheric electric field configurations. Our asymmetric electric field distribution contained an enhanced field in the dawnside northern hemisphere in conjunction with an enhanced field in the duskside southern hemisphere. From our study we have found the following: (1) In the geographic inertial frame the plasma flow patterns in both hemispheres exhibit significant variations with universal time because of the relative motion of the geomagnetic and geographic poles. (2) This universal time variation is greater in the southern polar region than in the northern polar region because of the greater displacement between the geomagnetic and geographic poles. (3) For the case of a uniform magnetospheric electric field the universal time dependence of the plasma flow distributions in the two hemispheres is similar, but there is a phase shift of about half a day between them. (4) For the case of an asymmetric magnetospheric electric field this half-day phase shift is still noticeable, but there are significant differences between northern and southern hemisphere convection patterns. (5) The transformation of plasma convection patterns from the geographic inertial to the geomagnetic quasi-inertial frame results in the same convection pattern for both hemispheres for the case of a uniform magnetospheric electric field, but results in different convection patterns for the two hemispheres for the more common case of an asymmetric electric field configuration. (6) Because the magnetospheric electric field distributions in the northern and southern polar regions are generally asymmetric, erroneous conclusions can be drawn about plasma convection patterns if data taken along satellite tracks from the northern and southern polar regions are overlaid. This is true whether the overlaying is done in the geomagnetic quasi-inertial frame or the geographic inertial frame.

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Abstract. We combined a simple plasma convection model with an ionospheric-atmospheric composition model in order to study the high-latitude winter F region at solar minimum for low magnetic activity. Our numerical study produced time dependent, three-dimensional ion density distributions for the ions NO^+, O_2^+, N_2^+, O^+, N^+, and He^+. We covered the high-latitude ionosphere above 54°N magnetic latitude and at altitudes between 160 and 800 km for a time period of one complete day. The main result we obtained was that high-latitude ionospheric features, such as the 'main trough,' the 'ionization hole,' the 'tongue of ionization,' the 'aurorally produced ionization peaks,' and the 'universal time effects,' are a natural consequence of the competition between the various chemical and transport processes known to be operating in the high-latitude ionosphere. In addition, we found that (1) the F region peak electron density at a given location and local time can vary by more than an order of magnitude, owing to the UT effect that results from the displacement between the geomagnetic and geographic poles; (2) a wide range of ion compositions can occur in the polar F region at different locations and times; (3) the minimum value for the electron density in the main trough is sensitive to nocturnal maintenance processes; (4) the depth and longitudinal extent of the main trough exhibit a significant UT dependence; (5) the way the auroral oval is positioned relative to the plasma convection pattern has an appreciable effect on the magnetic local time extent of the main trough; (6) the spatial extent, depth, and location of the polar ionization hole are UT dependent; (7) the level of ion production in the morning sector of the auroral oval has an appreciable effect on the location and spatial extent of the polar ionization hole; and (8) in the polar hole the F region peak electron density is below 300 km, and at 300 km, diffusion is a very important process for both O^+ and NO^+. Contrary to the suggestion based on an analysis of AE-C satellite data obtained in the polar hole that the concentration of NO^+ ions is chemically controlled, we find diffusion to be the dominant process at 300 km.

THEORETICAL PREDICTIONS FOR ION COMPOSITION IN THE HIGH-LATITUDE WINTER F-REGION FOR SOLAR MINIMUM AND LOW MAGNETIC ACTIVITY

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Abstract. We combined a simple plasma convection model with an ionospheric atmospheric density model in order to study the ion composition in the high-latitude winter F region at solar minimum for low geomagnetic activity. Our numerical study produced time-dependent, 3-dimensional, ion density distributions for the ions NO^+, O_2^+, N_2^+, O^+, N^+, and He^+. We covered the high-latitude ionosphere above 54°N magnetic latitude and at altitudes between 160 and 800 km for a time period of 1 complete day. From our study we found the following: (1) The ion composition exhibits a significant variation with latitude, local time, altitude, and universal time. (2) The variations of the ion composition with latitude and local time are in good agreement with the Atmosphere Explorer measurements both quantitatively and qualitatively. (3) At times and at certain locations the molecular ion density can be comparable to the O^+ density at 300 km, and at 200 km the O^+ density can be comparable to the molecular ion density. These results have important implications for the interpretation of incoherent scatter radar spectra obtained at high-latitudes. (4) Different ground-based observation sites should measure different diurnal variations in ion composition even if these sites are approximately at the same magnetic latitude owing to the UT response of the high-latitude ionosphere. (5) A satellite in a 300 km circular polar orbit should measure large orbit to orbit variations in both electron density and ion composition, again owing to the UT response of the polar ionosphere. (6) Erroneous conclusions can be drawn about ion density scale heights if the variations along the track of a satellite in a highly elliptical polar orbit are assumed to be only due to altitude variations.

Plasma Density Features Associated With Strong Convection in the Winter High-Latitude F Region

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We combined a simple plasma convection model with an ionospheric-atmospheric composition model in order to study the plasma density features associated with strong convection in the winter high-latitude *F* region. Our numerical study produced time-dependent, three-dimensional, ion density distributions for the ions NO^+, O_2^+, N_2^+, O^+, N^+, and He^+. We covered the high-latitude ionosphere above 42° N magnetic latitude and at altitudes between 160 and 800 km for a time period of one complete day. From our study, we found the following: (1) For strong convection, the electron density exhibits a significant variation with altitude, latitude, longitude, and universal time. A similar result was obtained in our previous study dealing with a weak convection model. (2) For strong convection, ionospheric features, such as the main trough, the aurorally produced ionization peaks, the polar hole, and the tongue of ionization, are evident but they are modified in comparison with those found for slow convection. (3) For strong convection, the tongue of ionization is much more pronounced than for weak convection. (4) The polar hole that is associated with quiet geomagnetic activity conditions does not form when the plasma convection is strong. (5) For strong convection, a new polar hole appears in the polar cap at certain universal times. This new polar hole is associated with large downward, electrodynamic plasma drifts. (6) For strong convection, the main or mid-latitude electron density trough is not as deep as that found for a weak convection model. However, it is still strongly UT dependent. (7) The ionospheric parameters N_mF_2, h_mF_2, and the topside plasma density scale height exhibit an appreciable variation over the polar region at a given UT.

Observations of the Diurnal Dependence of the High-Latitude *F* Region Ion Density by DMSP Satellites

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Data from the DMSP F2 and F4 satellites for the period December 5-10, 1979, have been used to study the diurnal dependence of the high-latitude ion density at 800-km altitude. A 24 hour periodicity in the minimum orbital density (MOD) during a crossing of the high-latitude region is observed in both the winter and summer hemispheres. The phase of the variation in MOD is such that it has a minimum during the 24-hour period between 0700 and 0900 UT. Both the long term variation of the high-latitude ion density on a time scale of days, and the orbit by orbit variations at the same geomagnetic location in the northern (winter) hemisphere for the magnetically quiet time period chosen show good qualitative agreement with the diurnal dependence predicted by a theoretical model of the ionospheric density at high latitudes under conditions of low convection speeds (Sojka et al., 1981a).

Seasonal Variations of the High-Latitude *F* Region for Strong Convection

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We combined a plasma convection model with an ionospheric-atmospheric composition model in order to study the seasonal variations of the high-latitude *F* region for strong convection. Our numerical study produced time-dependent, three-dimensional, ion density distributions for the ions NO^+, O_2^+, N_2^+, O^+, N^+, and He^+. We covered the high-latitude ionosphere above 42°N magnetic latitude and at altitudes between 160 and 800 km for a time period of one complete day. From our study we found the following: (1) For strong convection, the high-latitude ionosphere exhibits a significant UT variation both during winter and summer. (2) In general, the electron density is lower in winter than in summer. However, at certain universal times the electron density in the dayside polar cap is larger in winter than in summer owing to the effect of the mid-latitude 'winter anomaly' in combination with strong antisunward convection. (3) In both summer and winter, the major region of low electron density is associated with the main or mid-latitude trough. The trough is deeper and its local time extent is much greater in winter than in summer. (4) Typically, the electron density exhibits a much larger variation with altitude in winter than in summer. (5) The ion composition and molecular/atomic ion transition altitude are highly UT dependent in both summer and winter. (6) The ion composition also displays a significant seasonal variation. However, at a given location the seasonal variation can be opposite at different universal times. (7) High-speed convection cells should display a marked seasonal variation, with a much larger concentration of molecular ions near the *F* region peak in summer than in winter.